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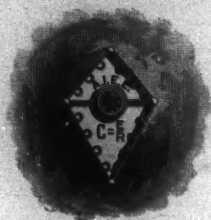
TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.



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*A paper presented at the 13th General Meeting of the
American Institute of Electrical Engineers,
New York, May 20th, 1896. Vice-President
Steinmetz in the Chair.*

THE RECONSTRUCTION OF THE PLANT OF THE CHICAGO BOARD OF TRADE.

BY BION J. ARNOLD.

When the writer agreed some four weeks ago to prepare a paper on the reconstruction of the plant in question, he hoped to be able to present to the INSTITUTE to-day some records of its operation, or data which would be of value, but owing to the delay in the arrival of certain parts of the plant, the question of operating it a sufficient length of time to secure such data proved impracticable, and not wishing to appear before this body with any data the completion of which did not extend over a sufficient length of time to make it reliable, he must confine himself to-day practically to a description of the plant, with the expectation of presenting to this INSTITUTE at a later date the records of its operation, in a form which he hopes will be of some permanent value. The plant involves a number of departures from the standard lines of office building engineering, and if the results of its operation are as successful as it now seems they will be after running a short period, the annual expenses of the operation of the plant will be reduced from \$25,000 to \$15,000, consequently its operation will be watched closely by those who have the matter immediately in charge.

The writer believes that all the energy required to produce motion and light in an office building should be developed in one set of steam engine cylinders and on one generator, having, of course, one set of cylinders and their generator in reserve. This set of cylinders, together with the working parts of the engine and its generator connected directly to it, constitute the unit which produces the energy of the plant, and this unit should be made to

work at its maximum economical load throughout its entire period of operation, while the energy from the unit should all be utilized during its running time. Having this idea constantly in view, the designer of this plant has planned to follow it out as closely as possible.

The old plant consisted originally of six horizontal tubular boilers operating at a steam pressure of about 75 to 80 pounds, and driving five small steam engines distributed in different

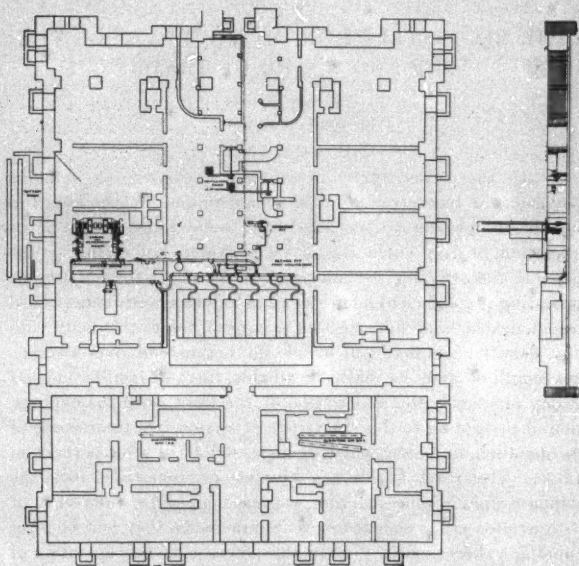


FIG. 1.

parts of the building, together with the necessary steam pumps, air compressors, etc., used for feeding the boilers, and operating the hydraulic elevators. Two of these engines were belted to a line shaft and drove several small incandescent and arc dynamos for lighting the building. The three other engines were used for driving the ventilating fans, three of which were located in the attic and two in the basement, and were driven by the engine by means of rope-drives with sheaves and ropes running at various

angles throughout the building. The elevators were driven by two horizontal compound direct-acting pumps, which consumed from 80 to 100 pounds of water per horse-power of energy delivered to the elevator cars. It became apparent after an examination of the plant that if the steam pressure could be increased to 125 pounds per square inch, so as to get the advantage of drier steam, and all the pumps in the plant which were consuming steam full stroke eliminated, and the energy of the plant produced by a compound condensing engine running at an economical load, that a large reduction in the operating expenses of the plant could be effected. The old boilers having been in use for about nine years, were almost ready to be condemned by the boiler inspectors, consequently it was an easy matter to decide upon replacing the boilers with heavier ones which would work at the above pressure. The adoption of a compound condensing engine to work under this increased steam pressure was a natural sequence which enabled the energy to be produced with the least possible coal consumption. After quite an extended investigation it was decided to supplant the hydraulic elevators with horizontal screw multiple sheave elevators, as the investigation showed that these machines could be operated for considerable less money per car mile than the hydraulic machines, under the conditions which existed in this plant. The operation of these elevators in practice has fully proven the correctness of this position. They have been in operation about four months now, on an average consumption of $4\frac{1}{2}$ kilowatt-hours per car mile, and as the duty required of them is exceptionally heavy, and the cars very large, this showing is very satisfactory.

The general plan of the plant is as follows:

Referring to Fig. 1, which represents the basement of the Chicago Board of Trade, the relative location of the different machines which enter into the plant can be determined. It will be seen that the installation consists of the following:—Five 66x16 ft. horizontal tubular boilers, designed to carry 125 pounds pressure per square inch; two 150 H. P. horizontal compound condensing engines running at 275 revolutions per minute, each directly connected to a 75 K. W. direct current generator, under a special system hereinafter described, which permits of either or both generators being driven from either engine. Four horizontal 30 H. P. multiple sheave elevators; six 10 H. P. electric motors, five of which operate ventilating fans, and one the machinery in

the total amount of energy required for the nine floors, and to join the floor leads or secondary mains onto each of these risers at their ends. With this arrangement it was possible to feed the secondary mains at two independent points, thus equalizing the pressure to better advantage and making the plant more reliable in operation. From the centre of these vertical risers, or at about the fifth floor, the main leads drop down each shaft, thence extend horizontally on the ceiling of the basement to the switchboard. Each of these mains which lead to the centre of distribution in each shaft are of sufficient carrying capacity to carry the total load of the building, exclusive of the basement, consequently if a fuse blows on either one of the mains, or if by any accident one of the mains should become broken or opened, the other main will carry the necessary current and keep the lights operating in the building. This precaution was taken owing to the fact that business matters of great importance are transacted in this building, and the loss of a few minutes at certain times would be disastrous to the men who operate in the building, consequently every precaution for safety and reliability had to be taken.

The basement circuit is independent of the above described mains, and consists of positive and negative leads, surrounding the entire basement of the building, from which are tapped the arc and incandescent lights used in the basement. The motor circuits are closely indicated in the diagram, and are independent of the lighting circuits, and are so planned that the starting rheostats of the motors are connected on the switchboard under the control of the engineer, thus making it possible for the engineer to start or stop any motor in the building without leaving the switchboard. The elevator circuits are also independent of the lighting and motor circuits, and it is possible to throw the current on or off any elevator at the switchboard. The batteries are located in a room adjoining the main engine room, and connected with the switchboard, as shown on the diagram.

The losses in wiring circuits of the building are computed as follows: Between generator and switchboard, one-half of one per cent.; between switchboard and centre of distribution, two and a half per cent.; from centre of distribution to secondary mains, one per cent.; between secondary mains and lights, one per cent.—making the total loss between generator terminals and lights five per cent.

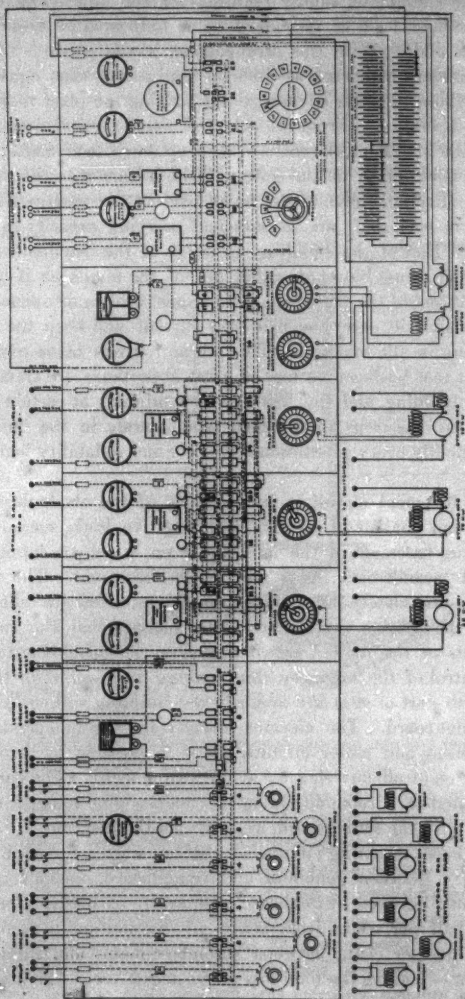


FIG. 8.

Fig. 3 represents largely diagrammatically the switchboard of the plant. From this it will be noticed that the plant is designed for three generators, but two of which are now in operation, as they are sufficient for the work. The lighting 'bus bars carry the main lighting circuits, controlled by switches 7, 8 and 9, and also the motor circuits controlled by switches 1, 2, 3, 4, 5 and 6. In the main lighting 'bus bar is placed a recording wattmeter, which registers all the energy delivered from the generator to the light and motor portions of the plant. In the elevator 'bus bars is placed another recording wattmeter, which registers all the energy delivered to the elevators from the lighting 'bus bars. With this arrangement and the means available in the plant for measuring the amount of coal and water consumed, the operators are enabled to keep accurate daily records of the cost per kilowatt of the energy produced and delivered by the plant. The diagram of the switchboard clearly shows the windings of the different generators and motors, and need not be further explained.

The generators are connected to the board by means of two switches, one of which is a triple-pole double-throw switch, and is arranged so that when thrown into the upper position it connects the generator to the elevator 'bus bar, using the compound winding of the generators. This arrangement permits the generator to operate the elevators and take care of the variable load without the use of the batteries. When the same switch, for instance No. 13 or 15 on the accompanying diagram, is thrown in its lower portion, the circuits are so arranged that the compound or series winding of the generator is cut out, and the equalizer connection from the generator becomes the positive connection, and the generator is connected to the elevator 'bus bars shunt wound, thus eliminating its series winding. With this arrangement, the generators and the batteries are run in multiple on the elevator load.

Referring now to the right-hand part of the board which is the storage battery portion proper, the operation is as follows: Under normal conditions, any elevator is operated shunt wound in parallel with the batteries by closing its corresponding switch, as, for instance, switch 15 for dynamo No. 3, downward the 15 *b* position. By closing switch 17 to 17 *a* position, the current passes from the positive elevator 'bus bar to the hand regulating cell switch, and out to cell No. 16, when the regulator is placed as shown

on the diagram. From cell 16 the current passes through the series of cells coming out at the negative end, thence through the proper conductor to the recording ammeter, thence to the overload switch and down to the negative terminal of switch No. 17 *a*. It will now be seen that whatever number of batteries are being operated in this series, are in parallel with the generator. The hand regulator is placed in the position indicated to enable the operator to cut in a sufficient number of cells in parallel with the generator, so that the cells will be constantly charging during the time of operation of the elevators, except at the temporary moments of overload caused by an excessive demand for current by the elevators. When this pull from the elevator occurs, the batteries respond and take the surplus load from the generator. With this arrangement, about fifty of the cells will be kept constantly charged, and in parallel with the elevators. In case the amount of current entering the cells is excessive between the intervals of heavy load on the elevators, the hand regulator is adjusted so as to cut in one or more cells until the current becomes reduced to the proper amount for the batteries; and, on the other hand, if the amount entering the cells is not enough to keep them properly charged, the hand regulator is adjusted so as to cut out a number of cells until the proper amount of current is reached. In the meantime, if the 15 end cells require charging, they are charged by means of the independent booster or motor generator in the manner hereinafter described. All the batteries can be operated in parallel with the generators when running shunt wound, in the same manner as they are used in conjunction with the elevator 'bus bars, by closing switch 17 downward to position 17 *b*. The connections for same can be easily followed on the diagram.

In order to operate the batteries in parallel with both the lighting and the elevator 'bus bars at the same time and maintain a practically constant voltage on the lighting 'bus bars, it is necessary to operate the generators shunt-wound instead of compound-wound. As before shown, the switches are so arranged that the compound winding of the generators can be utilized when the batteries are not in service, and the shunt winding used when the batteries are being run in parallel with the elevators and lights. Therefore, to maintain a practically constant voltage on the lighting 'bus bars and to run the elevators in parallel with the batteries at the same time, the operation is as follows:—Switch 17 *a*

is closed upward and operates as previously described in conjunction with the elevators and batteries. Switches 10, 12 and 14 are open to prevent the generators operating compound-wound on the lighting 'bus bars. Switch 16 is closed and the current passes as follows:—From the positive elevator 'bus bar through the switch 17 *a* to the center of the hand regulating switch, thence through the connection from the hand regulating switch to the corresponding cell (shown on the drawing as cell 16) thence through the series of 49 cells, out through the negative end and its corresponding connection, through the recording ammeter and overload switch, to the negative side of switch 17 *a*, thence to the negative elevator 'bus bar. It should be borne in mind that the lighting 'bus bars and the elevator 'bus bars are operating at different potentials, and that the potential on the elevator 'bus bars is changing slightly with the change of load, caused by variable load on the elevators. When the demand for current from the cells is great, as for instance when the elevator load is severe, the E. M. F. of the number of cells in parallel with the elevators necessarily drops, consequently the E. M. F. of the number of cells in parallel with the lighting bars, which includes all the cells working with the elevators, and a few of the regulating cells, would correspondingly drop, and some means must be provided to hold up the voltage of the lighting 'bus bars. This is accomplished by means of the automatic regulator which is controlled by a solenoid switch, shown in the upper right hand portion of the diagram. This solenoid switch operates by means of suitable connections to the lighting 'bus bars, in such a manner as to make and break the circuit through mercury cups as follows:—When the voltage of the lighting 'bus bars is reduced slightly, one side of the field of a right and left hand motor is thrown in, which causes the 'arm of the automatic regulator to move clock-wise, thus cutting in more cells in parallel with the lighting 'bus bars and holding the E. M. F. up. When the E. M. F. of the lighting 'bus bars reaches its proper voltage and tends to exceed it, the solenoid acts in the opposite direction and cuts in the left hand field of the automatic regulator motor, and brings the left hand field into service, causing the automatic regulator to rotate contra-clock-wise, thus cutting out cells until the voltage reaches the desired point. By this means a constant E. M. F. is maintained on the lighting 'bus bars, and the cells are worked in parallel with both the lighting and elevator 'bus bars.

It will be evident that the 15 end cells, or at any rate a portion of them when working in this manner, will become discharged through the day's run. After the batteries are cut off from the light, these end cells are re-charged as follows: Switch No. 23 is closed, thus throwing in the booster motor. As soon as the booster dynamo is brought up to speed, the underload switch is closed, and switch No. 22 closed upward, the operation then being as follows: From the positive brush of the generator end of the booster, which is producing energy at a low voltage, the current passes through the proper conductor to the centre of the automatic regulator; thence out through the regulator arm to segment No. 1, and through its proper connection to cell No. 1; thence through the first 15 cells to the wire leading off between the fifteenth and sixteenth cell. From this point it passes along the conductor, through switch No. 23 to the underload switch; and from the underload switch back to the negative side of the booster generator. By means of a field rheostat, located on the switchboard, the E. M. F. of the booster generator is regulated and adjusted to correspond to the number of end cells which are being charged.

To charge all the cells in series from one of the main generators, it is necessary to increase the E. M. F. a sufficient amount to overcome the total voltage of the cells. This is done by placing the generator portion of the booster or motor-generator in series with the main generator as follows: Switch No. 23 is closed, thus throwing in the booster motor and at the same time energizing the fields of the booster dynamo. The booster motor is now started by means of its rheostat and brought up to speed. Switch No. 22 is closed downward, the path of the current then being as follows: From positive lighting 'bus bar through switch 22, to the underload switch, thence to the negative brush of the booster dynamo, out through the positive brush to centre of the automatic regulator, through this arm to segment No. 1, and thence through suitable connection to cell No. 1; through the entire series of cells to the negative lead, thence through the recording ammeter and overload switch; back through switch 22 to the negative lighting 'bus bar. The operations for manipulating the entire plant being then as follows:—

To charge all the cells in series with the main generator by means of the booster: Open switches 16 and 17 and close switches 23 and 22 down.

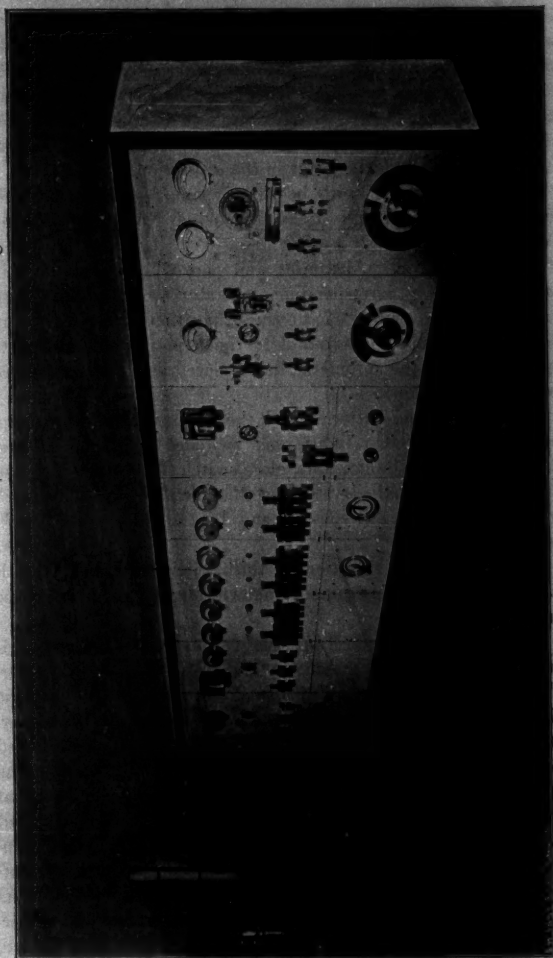


FIG. 4.

To charge all the batteries, except the end cells, at the same time operate light and elevators from one dynamo. Place hand regulator on segment 16, connect whatever dynamo is in use to elevator 'bus bar by means of its elevator switch, either 11, 13 or 15, in the *b* position. Disconnect dynamo from lighting 'bus bars by opening its corresponding switch, either 10, 12 or 14, and see that switches 22 and 23 are open, and that switches 16 and 17 are closed, the latter in the *a* position.

To charge end cells with booster dynamo:—Place automatic regulator on segment No. 1, see that switch No. 16 is open, and close switches 23 and 22 up.

To place elevators, batteries and one of the generators in parallel, close the corresponding generator switch to the *b* position, and close switch 17 to the *a* position, if desired to run through the hand regulator, and to the *b* position if desired to operate through the automatic, but if placed in the *b* position, see that switch 16 is open.

To discharge the batteries with the generators shut down, operate as follows: On lights, open switches No. 22 and 23, and close switch 16. On elevators, close switch 17 to the *a* position. To operate lights and elevators, see that switches No. 22 and 23 are open, and close switches 16 and 17, the latter to the *b* position.

Fig. 4 shows the elevation of this switchboard, and from it the position of the instruments shown on the diagram can be easily located.

The method of connecting the engines and generators is shown in Fig. 5, and represents a system planned by the writer, which enables a direct coupled plant to be so built as to have the advantage of an independent unit direct coupled plant, when operating under normal conditions, and all the flexibility of a belted plant in case of accident to any particular part of the plant. The cut shows the plan, elevation and section. It will be noticed that at present there are but two generators and two engines; but when extensions are needed, the right hand engine will be disconnected from its present dynamo, and moved to the right a sufficient distance to allow the placing of an engine of double its capacity in the same position it now occupies, and two generators between the middle engine and the right hand engine, thus making a plant with three engine units and four generator units, all four of which are available from the middle engine,

and two of which are available from each of the outside engines. Referring to the sectional view, *a a* represents the ends of the engine shafts which carry disks *h h*. The generators are mounted upon hollow sleeves or quills, which are supported in independent bearings, *p p* and *p p*. The ends of these quills are enlarged to form flanges corresponding in diameter and thickness to the engine flanges. Between engine shafts *a a* extends an

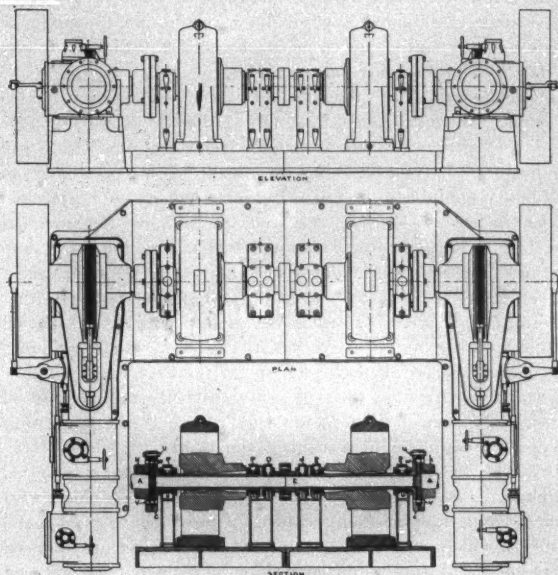


FIG. 5.

auxiliary shaft, *e* (coupled at its centre, in this case, to permit half of the plant being put in operation before the other half is ready). and carried in independent bearings, *d d*. This shaft, *e*, carries at each end circular disks, which in this case are forged solid with the shaft. Under normal conditions shaft *e* does not revolve, but lies passive in bearings *d d*, and the engines drive the generators direct coupled, by inserting the bolts *u u*, three of which, spaced 120° apart, are used in each coupling. It is now evident

that each engine is operating an independent unit direct coupled generator without revolving any more shafting or machinery than is usual in ordinary independent unit direct coupled plants, inasmuch as the quills which surround the auxiliary shaft ϵ do not come in contact with it, but have a clearance of one-quarter of an inch all around it. If from any cause it becomes desirable to drive the left hand generator from the right hand engine, it is done as follows: In the openings v , three of which are provided 120° apart, are placed taper bolts which couple the auxiliary shaft ϵ solidly on the engine shaft a by means of disk h . Taper bolts are also placed in spaces w , which couples shaft ϵ to the quill of the left hand generator. By removing bolts u , which disconnect the left hand generator from the left hand engine, the left hand generator can now be driven from the right hand engine, and the right hand generator continues in operation from the same engine, if desired. By removing u , the right hand generator becomes disconnected from the right hand engine, and the left hand generator is being driven from the right hand engine. In the same manner the right hand generator can be driven from the left hand engine, or both generators from either one of the engines. By using compound engines, so designed that by working high pressure steam in the low pressure cylinder, one engine can be made to double its power for a few hours. The plant has thus the total generator capacity available at all times, and allows one engine to be in reserve for repairs, thus doing away with the investment of the third unit, which is usually carried in such plants for safety. The system, when used without the battery auxiliary instead of being provided with bolted connections as here shown, is provided with magnetic clutches, which permit the generators to be brought up to speed as motors, and thrown in connection with the engines without stopping either engine in use. This makes it possible to connect either generator with either engine without shutting down the plant in any part. With such an arrangement, with the engine and generators equal to the maximum capacity of the plant, and battery auxiliary equal to one-third the capacity of the plant, any office building can be operated in the most economical manner, according to the writer's belief, for when the battery is in operating order, one unit in conjunction with the battery handles the plant economically and satisfactorily, leaving one engine unit in reserve. In case the battery is out of service, both units can be

operated until the battery is ready for service again, and during the light load period the battery auxiliary takes care of the entire service of the building, without the use of either the engine or generator units.

The engines are operated during the summer compound condensing, by using a cooling pan system and siphon condenser, as shown in section at the right hand of Fig. 1. With this arrangement the condensing water is cooled by means of the 72" ventilating fan which is in operation during the entire 16 hour run of the plant, and is used for ventilating the building. It was thought advisable to utilize the air from this fan for cooling the water, inasmuch as the energy for driving the fan had to be produced, and utilizing the air from the fan would not entail any additional expenditure of energy upon the plant over that required under ordinary conditions. The condenser is placed near the ceiling of the boiler room and delivers into the standpipe extending downward into a pit about 35 feet. From the bottom of the pit a direct acting deep well pump lifts the water and delivers it to the cooling pans. From the cooling pans the water reaches through suitable piping the cistern shown on Fig. 1. From this cistern the injection pipe from the condenser leads. For this reason the plant will operate about six months of the year compound condensing, and during the balance of the year compound non-condensing, when the steam from the engines will be run into the mains of the building and used for steam heating.

Fig. 6 represents the load diagram of this plant.¹ The parallelogram A, B, C, D, representing the total capacity in kilowatt hours of one of the generator units, assuming that the unit starts at seven o'clock A. M. and operates until eleven o'clock P. M. The line *a, b, c, d, e, f, g, h, i, j, k, l, m*, represents the load line, or energy required by the building during the same period. That portion of the diagram shaded with lines inclining to the right at an angle of 45° represents the amount of energy passing into the batteries, while the portion of the diagram represented by shade lines inclining to the left at an angle of 45° represents the amount of energy delivered from the batteries. It will be noticed that from 11 P. M. until 7 A. M. the entire load of the plant is operated by the batteries alone. With this arrangement but two shifts of labor are required, one operating from 7 A. M. until 3 P. M., and the other from 3 P. M. until 11 P. M. From 11 P. M.

1. For this diagram see p. 648, vol. xii.

until morning during the winter the watchman acts as fireman for the boilers to maintain the steam heat in the building. This diagram having previously been illustrated in the *TRANSACTIONS* of the *INSTITUTE* November 1895, it will not further be described here, except to state that the various lines shown on the diagram represent the loads of the different motors, elevators, etc., and the periods during which they operate. The writer hopes in the future to present to the *INSTITUTE* a new diagram representing the actual load lines of the plant, compiled from statistics covering its operation for a considerable length of time, and it will then be interesting to compare the actual diagram with this one which was prepared before starting to design the plant.

DISCUSSION.

MR. WOLCOTT:—I would like to ask Mr. Arnold whether it would be cheaper to use some gas now in that building or to use the battery a little more and dispense with the gas. He says some gas is used, as I understand him. I notice that there is a sudden drop in the load at 5:30 P. M. when the gas is turned on, and that allows the surplus current to go into the battery. If that gas were not used, the diagram would be of a considerably different shape.

MR. ARNOLD:—This diagram was prepared in my office before the method of re-constructing the plant was decided upon, and the various lines represent the different motors, elevators, etc., as we supposed they would operate in practice. The point marked "gas turned on" is the time they turn the gas on now,—not what it will be in operation, because we propose to turn the gas off entirely. This diagram was prepared over a year ago. In all probability, within six months from now I will be able to give you a diagram showing what the actual load line of the plant is.

MR. J. W. LIEB, JR.:—I would like to ask Mr. Arnold why it is that in the plant he describes the peak of the load occurs between 11 A. M. and 1 P. M.

MR. ARNOLD:—That is the time when the people connected with the Chicago Board of Trade are most excited. The Board opens at 9.30 o'clock in the morning. At 12.30 they go to their offices and figure up what they have made or lost, consequently the office lights are used most at this time, and some of the motors shown running at this particular period are shut off at a later period, which also accounts for a part of the load.

MR. RIES:—I would like to ask Mr. Arnold to explain a little more fully the precise conditions under which—referring to Fig. 5—one steam engine is cut off and the other one is connected to the intermediate shaft to drive both dynamos. It would seem that this arrangement would not prove very practicable

under full loads, unless the engines are each capable of being worked to double their normal capacity, thereby requiring larger engines than would be employed in ordinary direct-driving installations. But, perhaps, Mr. Arnold may have special reasons for the construction illustrated. What is the object of that?

MR. ARNOLD:—That is a condition that sometimes arises. Suppose one engine and the generator attached to the other engine should become disabled, your plant would then be completely shut down if independent units were employed, unless you had a third unit to put in operation. Such a thing is liable to happen, and it is for this emergency that this arrangement is specially adapted, although there are other advantages.

MR. RIES:—Then my understanding of the matter is correct in assuming that each engine is only of sufficient power to operate *one* of the two dynamos at a time, and that it is only in case of the disablement of *one* of the engines and the *opposite* dynamo that the combination alluded to is supposed to be utilized.

MR. ARNOLD:—Suppose the battery should be out of service and one engine should become disabled. You would then be obliged to have the full capacity of both generators to operate the plant. The way these engines are designed and piped, you can double the capacity of either engine, and drive both generators to their full capacity from either engine, while the breakdown is in existence.

MR. RIES:—Isn't this construction somewhat complicated, as against the use of a separate engine and dynamo held as reserve?

MR. ARNOLD:—No, it is not complicated, costs very much less money than a third unit, and gives the same reliability.

MR. RIES:—Then the magnetic clutch, to which you referred. I suppose that it is intended to disconnect the disabled engine from the main shaft, leaving the internal shaft to drive both dynamos?

MR. ARNOLD:—Yes, sir.

MR. RIES:—And as to the magnetic clutch connecting the intermediate shaft?

MR. ARNOLD:—That is a double clutch whereby you can connect either generator to its corresponding engine, or you can also connect the interior shaft to either engine, or connect either generator to the interior shaft. It works both ways. I want to state that I do not wish too much stress to be put upon this magnetic clutch question at this time, because I have not yet developed it to a point where I am able to say what it will or will not do; but I thoroughly believe in such clutches, and am now engaged in developing a formula to build them by. The other mechanical connections are now in operation, and they are successful.

MR. RIES:—I simply wanted, Mr. Chairman, to get a little further explanation as to the reasons for this peculiar construction.

MR. ARNOLD:—There are a number of advantages to this thing, which, as the plant increases in size, become apparent. I have not said anything about them in this paper. The paper

was prepared simply to show the general plan of the plant, and this arrangement being somewhat of a hobby of mine. I have mentioned it as little as possible, except enough to give the general idea of its make up.

MR. DOUGLASS BURNETT:—We are bound to admire the care which Mr. Arnold has bestowed upon all the details of this plant, and observing that a great deal of information is available, I desire to draw upon him for a little of it.

First,—as to any trouble he may have experienced with motor load; is not a large proportion of the output between 11 A. M. and 1 P. M. absorbed by motors, and does he find it desirable at that time to run separate engines for the two classes of service—lighting and power? Under those panicky conditions to which he refers, what is the maximum number of amperes which he might be called upon to supply?

The car mile consumption of his elevators has been given on page 275 as $4\frac{1}{2}$ k. w. hours. I very much wish that that number of k. w. hours could be translated into cents; in other words, what does current cost him per k. w. hour?

Finally, as to the load curve: How does this theoretical diagram work out in practice? Does it coincide substantially with one which would be obtained by observation? We presume that it was designed for a winter's day,—that is, maximum condition, and not for the average of an entire year. We trust that Mr. Arnold will enlighten us upon these points.

MR. ARNOLD:—The black line represents the total load of the plant on an ordinary day. The dotted line above represents the maximum load of the plant on a dark day. In other words, our Chicago weather is so uncertain that it very often happens that the sun may be shining, and suddenly a cloud will come up and darken the sky over the city, so that all the lights in the building will need to be turned on. It is under those conditions that the upper dotted line was prepared. In that case the plant would be at full load, but the surplus would have to come from the second generator or battery auxiliary. That is another case where the second generator would be run by the opposite engine. The average light day load is shown by the dotted line immediately under the heavy line; the other being the maximum or dark day load. Both engines and generators will handle the maximum day load conveniently. One generator and the battery auxiliary will handle the maximum load without difficulty.

I hope to be able to get the cost for fuel down to a sum not exceeding $1\frac{1}{2}$ cents per k. w. hour. At some stations we are doing it at four-tenths of a cent per hour, where bituminous slack coal is worth ninety cents per ton. I think I will be able to show the INSTITUTE, in six months from now, a record of cost of coal per kilowatt hour of one cent from this plant. Under those conditions, four and a quarter cents per kilowatt hour means four and a quarter cents per car mile of travel on the elevators.

Adding to that the cost of labor, I think I will show you a record of running those elevators at a cost not exceeding eleven or twelve cents per car mile, whereas it is now costing eighteen to twenty cents per car mile for hydraulic elevators. In this connection I will state that I have tested a number of electric elevators in Chicago, for one of the large elevator corporations, and I find that the consumption of energy per car mile of travel varies from four to eleven kilowatt hours. I hope to be able to operate these cars at a cost of not over six cents per car mile for fuel alone. This is nothing but what anybody could do who would take these conditions and study them and make the most of everything available.

MR. BURNETT:—We thank Mr. Arnold very much. However, we wish he could state the actual maximum current required to run the elevators in that building. I should also like to ask if he can give us the total kilowatt hours generated during a year.

MR. ARNOLD:—I do not know that there is any hesitancy on my part in giving that information. The current taken by the two machines now in operation,—I mean the starting current, when starting a live load of 3000 pounds, together with the weight of the car,—reaches as high as 600 amperes at 125 volts. That is the service. It should be borne in mind, that the particular elevators there in use consume no current on the down trip; consequently the average consumption of current per car mile is low as compared with some elevators which consume current both going up and coming down, although not so high a starting current. The figures of $4\frac{1}{2}$ kilowatt hours per car mile are correct, because they are taken from a watt-meter which has been running now for four months. Indeed, that is the only figure that I felt absolutely safe in giving regarding the operation of the plant at present.

MR. LIEB:—I am sure that we all appreciate the careful preparation of Mr. Arnold's paper. I can only express the hope that when the plant has been in operation a sufficiently long time, Mr. Arnold may keep his promise and give us in some detail the operating costs. The question of the cost of current production in a plant of this character is an important one, and there is a great lack of reliable information sufficiently detailed to be of use in making comparisons. Usually many of the important items of cost are left out of consideration, and, if Mr. Arnold will permit me, I would suggest that in making up his analysis for future presentation to the INSTITUTE, he might with advantage follow the lines of some of the blanks used for that purpose by the large illuminating companies, which give the items of cost under appropriate heads. I think such a paper would be a valuable contribution, and the discussion would bring out important and interesting data. There are not many plants of the size of the one described by Mr. Arnold operated as an isolated plant and which have such a combination of elevator load, lighting load, and motor load. The arrangement of gener-

ating machinery, which he has adopted in his installation, would give valuable data for comparison, and for my part I hope that Mr. Arnold will fulfill his promise, and in due course of time present to the INSTITUTE details of operating cost.

MR. RIES:—It strikes me that the most valuable feature, probably, of Mr. Arnold's proposed installation is the extended use which he makes of secondary batteries in connection with the dynamo. Some years ago, I had occasion to devise a system somewhat analogous to this, for railway work, and from the revived interest which has been manifested of late in the secondary battery, I think it will be but a short time before the battery is very largely used both in stationary service and in railway installation. I notice, on referring to the diagram, Fig. 6, that the battery is very largely drawn upon between 11 and 1 o'clock in the day time, and between 11 o'clock at night and 7 o'clock in the morning. This would indicate from the abruptness of the lines that the battery is switched onto the service mains independently of the dynamos. But I would like to ask Mr. Arnold whether he also uses the battery as a regulator to render the load on the dynamo continuous or practically uniform while the dynamo is running and supplying these various forms of service?

MR. ARNOLD:—I use two regulators, one a hand regulator, and the other an automatic regulator. The hand regulator is adjusted by the engineer at a proper point, so that a certain number of the cells are used in parallel with the elevators; or, rather, so that the total voltage of whatever cells are used in parallel with the elevator is just enough less than the voltage of the dynamos to allow the cells to receive a constant charge, except when the maximum pull comes on the elevators. At all other times the batteries are in parallel and are receiving a charge. Then the regulated cells are charged by means of the generator end of the motor-generator, and the entire series of cells is charged by means of the generator end of the booster running in series with the main dynamo.

MR. RIES:—The batteries are in parallel with the dynamos, and in case of any sudden fluctuation of load, the batteries supply the deficiency?

MR. ARNOLD:—Yes, sir.

[At this point the President resumed the Chair.]

THE PRESIDENT:—Gentlemen, is there any further business to bring before the meeting?

THE SECRETARY:—We have an invitation from Mr. George Hill to visit the plant of the American Book Company on University Place. We also have an invitation from the Crocker-Wheeler Electric Company to visit their works. Both have already been announced.

On motion, the thanks of the INSTITUTE were tendered to the National Electrical Exposition Company for the privilege of occupying their convention hall, and for courtesies extended.

[Adjourned.]

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, September 23, 1896.

The 108th meeting of the INSTITUTE was held this date at 12 West 31st Street, and was called to order by President Duncan at 8.30 P. M.

THE PRESIDENT:—The Secretary has some announcements to make.

SECRETARY POPE:—At the meeting of the Executive Committee of the Council, August 5th and September 23d, the following associate members were elected :

Name.	Address.	Endorsed by
ABELLA, JUAN	Director General of Public Lighting, Buenos Aires ; residence, 691 Calle Bolivar, Buenos Aires, Argentine Republic.	W. G. Whitmore. J. C. Bennett. M. L. Mora.
APPLEYARD, ARTHUR E.	Manager and Engineer, Natick Gas and Electric Co., Natick, Mass.	Geo. W. Blodgett. Robt. B. Taber. I. N. Farnham.
BARRY, DAVID	Electrician and Superintendent, Amherst Gas Co., Amherst, Mass.	J. B. Cahoon. C. B. Burleigh. Giles Taintor.
BELL, ORO A.	Electrical Engineer, Western Electric Co., 22 Thames Street, New York ; residence, 921 St. Nicholas Avenue, New York.	H. F. Albright. Geo. A. Hamilton. J. J. Carty.
BETTS, HOBART D.	Member of Inspection Dept., The Edison Elec. Ill'm'g Co. of N. Y. ; residence, Englewood, N. J.	J. W. Lieb, Jr. C. R. Agnew. C. L. Eldlitz.
BIDDLE, JAMES G.	Mfrs' Agent and Importer Scientific and Electrical Instruments, 944 Drexel Bldg, Philadelphia, Pa. ; residence, 364 Rittenhouse St., Germantown, Pa.	E. G. Willyoung. Herbert Lloyd. R. W. Pope.
BOLAN, THOMAS V.	Supervising Engineer, The Gen'l Electric Co., Schenectady, N. Y. ; residence, 869 N. 41st St., Philadelphia, Pa.	H. G. Reist. Ernst Berg. Chas. P. Steinmetz.
BRAYSHAW, I.	Telegraph Inspector Great Southern Railway, Buenos Aires.	Henry Jackson. W. H. Preece. R. W. Pope.

ASSOCIATE MEMBERS ELECTED.

CARPENTER, CHAS. E.	Vice-President, Carpenter Enamel Rheostat Co.; residence, 36 W. 85th Street, New York.	H. F. Albright. G. A. Hamilton. Ralph W. Pope.
CODY, L. P.	Manager and Engineer, Grand Rapids Electric Co., 9 South Division Street, Grand Rapids, Mich.	Chas R Cross. Frank B Rae. A. F. Walker.
DARROW, ELEAZAR	Superintendent, Cincinnati Edison Elec. Co.; residence, 290 W. 8th St., Cincinnati, O.	J. A. Cabot. Thos. J. Creaghead. L. G. Lilley.
GRANBERY, JULIAN H.	Draughtsman, with Post & McCord, 289 4th Ave., N. Y.; residence, Closter, N. J.	Clayton W. Pike. A. A. Knudson. R. W. Pope.
GREENLEAF, LEWIS STONE	Electrical Expert, The American Bell Telephone Co., 42 Farnsworth St.; residence, "The Ludlow," Clarendon St., Boston Mass.	Chas. R. Cross. Russell Robb. Theo. Spencer.
HADLEY, FRED'K W.	Electrical Engineer, West End St. R'way Co., Boston; residence, Arlington Heights, Mass.	Chas. R. Cross. Wm. L. Puffer. Chas. F. Scott.
HALL, J. P.	Electrical Contractor, 143 Liberty St., N. Y.; residence, 200 W. 136th St., N. Y.	E. S. Keefer. J. Hatzel. Frank A. Pattison.
HATHAWAY, JOSEPH D., JR.	Assistant in Cable Dep't Western Electric Co., 22 Thames St., N. Y. City.	H. F. Albright. G. A. Hamilton. M. E. Canfield.
HILL, NICHOLAS S., JR.	Engineer of the Electrical Commission of Baltimore, 508 Equitable Building, Baltimore, Md.	Louis Duncan. Joseph Wetzler. Henry Morton.
HUGGINS, N. W.	Salesman, etc., General Electric Co., Seattle, Wash.	S. Z. Mitchell. F. L. Dame. F. B. H. Paine.
KING, VINCENT C., JR.	With V. C. & C. V. King, 517 West St.; residence, 110 East 16th St., New York.	Joseph Broich. Joseph Sachs. R. W. Pope.
LABOUISEE, JOHN PETER	1625 Thalia St. New Orleans, La.	Brown Ayres. P. R. Middlemiss. Chas. K. Huguet.
LORIMER, GEO. WM.	Superintendent of Construction, The Callender Telephone Exchange Co., Bradford, Canada.	Romaine Callender. Joseph Wetzler. Otto A. Moses.
LORIMER, JAMES H.	Superintendent of Erection, The Callender Telephone Exchange Co., Brantford, Canada.	Romaine Callender. Joseph Wetzler. Otto A. Moses.
MACLEOD, GEORGE	Superintendent and Engineer, Kentucky and Indiana Bridge Co., 29th and High Sts., Louisville, Ky; residence, New Albany, Ind.	G. W. Hubley. R. W. Pope. W. D. Weaver.
MAKI, HEIICHI	Chief Engineer, Kioto Traction Co., 39 Washio St., Kioto, Japan.	Chas. R. Cross. Wm. L. Puffer. Albert Schmid.
MAXWELL, EUGENE	Superintendent, Third Street and Suburban R'way Company, Seattle, Wash.	S. Z. Mitchell. F. L. Dame. F. B. H. Paine.

McKITTRICK, F. J. A.	Graduate Student Cornell University, 89 Heustis Street, Ithaca, N. Y.	Edw. L. Nichols. Fred'k Bedell. C. P. Matthews.
MORGAN, CHAS. H.	Student Lehigh University; residence, Maxatawny, Berks Co., Pa.	Alex. Macfarlane. J. H. Klinck. Frank M. Tait.
NOCK, GEO. W.	Chief Engineer, in charge of Steam and Electric Plant Westinghouse Elec. and Mfg. Co., Pittsburgh, Pa.	Philip A. Lange. L. A. Osborne. Leo A. Phillips.
PARKER, LEE HAMILTON	Ass't Engineer Railway Dept., General Electric Co., Schenectady, N. Y.	W. B. Potter. John B. Blood. Edw. M. Hewlett.
PIKE, ALEX. REA	In charge Testing Dept., Missouri Electric Light and Power Co., 20th and Locust Sts., St. Louis, Mo.	Geo. H. Morse. A. L. Reinmann. Francis Jehl.
RIDEOUT, ALEXANDER C.	Principal of Commercial and Telegraph Dep't Hillsdale College, Hillsdale, Mich.	B. J. Arnold. W. M. Stine. R. W. Pope.
SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.	Herman S. Hering. A. M. Schoen. C. K. Stearns.
SATHERBERG, CARL HUGO	Mechanical Engineer and Chief Draughtsman The Midvale Steel Co., Nicetown, Phila. Pa.; residence, 1752 N. 26th St., Philadelphia, Pa.	Clayton W. Pike. Carl Hering. C. Billberg.
SCOTT, JAMES B.	Electrical and Mechanical Engineer, 227 East German Street, Baltimore, Md.	H. A. Foster. P. O. Keilholtz. C. G. Young.
THAYER, GEORGE LANGSTAFF	Manager, Belle Plaine Electric Light Co., Belle Plaine, Ia.	Ludwig Gutmann B. J. Arnold. Carl K. MacFadden
VAN VLECK, JOHN FALCONER	Constructing Engineer, The Edison Elec. and Illuminating Co. of New York; residence, Glenridge, N. J.	Edwin J. Houston. A. E. Kennelly. J. W. Lieb, Jr.
WHITAKER, S. EDGAR	The General Electric Co.; residence, 93 High Rock Avenue, Lynn, Mass.	Chas. R. Cross. Wm. L. Puffer. Elmer E. Boyer.
Total 37.		

ELECTED SEPTEMBER 23d, 1896.

Name.	Address.	Endorsed by
BRINCKERHOFF, HENRY MORTON	Electrical Engineer, Metropolitan West Side Elevated R R.; 258 Franklin St., Chicago, Ill.	A. V. Abbott. W. M. Stine. B. J. Arnold.
MEADOWS, HAROLD GREGORY	Associate Engineer (Elec.) with Newcomb Carlton, 109 White Building; residence, 114 West Chippewa St., Buffalo, N. Y.	C. A. Adams, Jr. Edwin H. Hall. C. W. Ricker.

ASSOCIATE MEMBERS ELECTED.

NEWBURY, F. J.	Manager Insulated Wire Dep't John A. Roebling's Sons Co., Trenton, N. J.	M. M. Davis. F. W. Roebling. R. W. Pope.
PINKAS, JULIO,	Director General, State Telegraphs and Telephones, Sucre, Bolivia.	R. W. Pope. Max Osterberg. A. A. Knudson.
RICHARDS, CHAS. W.	Partner, Cumner-Richards Co., 69 Broad St., Boston; resi- dence, Needham, Mass.	A. B. Cumner. F. E. Cabot. G. A. Wardlaw.
WHITE, CHAS. G.	Public Schools Sup't., and Instruc- tor in Physics and Chemistry, Lake Linden, Mich.	R. W. Pope. W. D. Weaver. Wm. J. Hammer.
Total, 6.		

At the request of the President, Mr. Charles P. Steinmetz, Vice-President, took the Chair. President Duncan then delivered his inaugural address on the "Present Status of the Distribution and Transmission of Electrical Energy," as follows:

PRESENT STATUS OF THE TRANSMISSION AND DISTRIBUTION OF ELECTRICAL ENERGY.

BY LOUIS DUNCAN.

The industrial life of mankind is made up of two things. The transformation and distribution of material, and the transformation and distribution of energy. The raw material from mines and forests is changed to finished products and distributed among the people, while energy, obtained from water power, coal or other sources, is changed from the potential energy of the water, or the energy of chemical combination to mechanical power, heat, light, etc. Unless we can transmit this energy economically, we must transform it into the required form at the place where it is to be utilized. At present a large part of our mechanical power is obtained from steam plants situated in the factories themselves, and for heat and light we mainly depend upon stoves and lamps in our houses.

Before the introduction of electrical transmission, it was possible to distribute energy to limited distances by various methods, but no system offered a long distance transmission for all purposes. By means of compressed air or steam pipes the energy of coal has been transmitted to produce mechanical power or for heating, and gas mains have allowed the distribution of gas for lighting or for fuel.

In the case of power obtained from steam plants the economy incidental to large units and a steady load, has lead to the concentration of industries. Where steam is used, the plants are situated where it is most convenient for manufacture. Where water power is employed it is necessary to bring the factories to the location of the power irrespective of other conditions.

By means of dynamo electric machines, the energy obtained from either coal or water power may be transformed into electrical energy; may be distributed and then transformed again into mechanical power, light or heat, or may be used for a number of purposes peculiar to this form of energy alone. The limits to the distance of this distribution are imposed by conditions of economy and safety.

It is my purpose to take up the different methods of transmission and distribution and to consider the limits that are actually fixed by the present status of electrical development. The question is a commercial one, each problem presenting different conditions which must be considered, but certain general principles govern each case, and our knowledge and experience makes it possible to judge the practicability of each particular transmission.

GENERATING PLANTS.

At the present time practically all of the electrical energy distributed is generated in plants operated either by steam or water power, and it is important to consider the conditions of maximum economy in large generating plants, as this bears directly on the subject of transmission and distribution.

A large proportion of the electrical plants in this country are steam plants. In the last ten years we have advanced from small stations using high speed dynamos for light and power distribution, to large stations, using, as a rule, low speed direct connected machines. The simple engines that were used some years ago have, in many cases, been changed to compound and even triple expansion engines, and where it is possible condensers have been employed. Some of the latest plants have machinery of the highest possible efficiency, and yet if we consider the price per H. P. of the power generated, we will find that it is greater than we expect. This is partly due to the fact that for both lighting and power purposes the load on the station, is, as a rule, not uniform and the apparatus is not working under the best conditions for economy. In this country electrical energy is principally generated for electric lighting, for electric traction, and for supplying stationary motors, the stationary motors, as a rule, being supplied with current from lighting stations. If we take the load diagram of such stations in large towns, we will find that the average output is not greater than 30 to 40 per cent. of the maximum output. We have, therefore, to supply a large amount of

machinery corresponding to the maximum demand on the station, while for distribution a large amount of copper is required that is only being used at its maximum capacity for a comparatively short period of the time. In stations supplying power for traction purposes we find a variation of load, but the variation is a different kind from that found in a lighting station. In the latter the load varies at different hours in the day, but for any particular instant it is practically constant. In the former the average load for different hours during which the station is operated will be practically constant, but there will be momentary variations depending upon the size of the station and the type of traffic. Taking for instance a 2000 H. P. station in Baltimore, I find that the average load is 48 per cent. of the momentary maximum load. This difference in the kind of variation for the two types of stations necessitates employment of different apparatus to obtain the maximum economy for each type. For lighting stations triple expansion engines may be used, while for traction work, where the variation in the load is sudden and may occur after the steam is cut off from the high pressure cylinder, it is not well in general to go beyond compound engines, and there is even a question as to whether simple engines are not more economical when condensing water cannot be obtained. In any case, however, it is of the utmost importance as regards economy of operation that the load should be made as constant as possible.

Two distinct types of distribution are used for incandescent lighting in this country—the single-phase alternating current and the direct current three-wire system. At the present time the former does not permit the supplying of power. As alternating distribution is at high potential it does permit the location of the station where the conditions of maximum economy can be fulfilled. The three-wire incandescent system using low voltages may be used for supplying motors, but the amount of copper necessitated by the low pressure has caused such stations to be located near the centre of distribution irrespective of the best conditions for the economical operation of the plant.

With the alternating system it seems impossible to provide even a moderately steady output, but with the continuous current system the motor load during the day gives an average output greater in proportion to the maximum. Some years ago the question of the relative values of the alternating and direct current systems was discussed, and for a while most of the stations

installed were of the alternating type. At present the tendency seems rather in the direction of continuous current stations, especially in towns where there is a large demand for current within a comparatively small area. There is a great advantage of direct currents in that they allow the employment of storage batteries, which equalizes the load on the station. In almost all of the large lighting plants, both here and abroad, this plan has been adopted to a greater or less extent and the results have been so favorable that the battery equipments in many of our stations are being increased. The efficiency of batteries in lighting stations is comparatively high, while the depreciation has been greatly reduced, and is not now over five or six per cent. per annum. In most systems, however, the full benefit of the storage batteries is not realized, as the batteries are placed in the station, and while the advantage of an approximately constant load is obtained, yet the further advantage offered in distribution is not secured. I will take this question up later.

In New York, Brooklyn, Boston and Chicago a large proportion of the direct current lighting stations are situated where it is expensive to handle the coal and ashes, and where the economy, due to condensation, is not obtained. It is also the custom to use several stations instead of a single large station, and this increases the cost of production both in operating expenses and fixed charges. The question arises whether we have reached a point where it will be more economical to consolidate the stations in the best possible location for economical production of energy, and make use of the means of distribution which have been developed in the last few years to increase the radius at which energy can be supplied.

As far as traction stations are concerned, their efficiency and output would be increased by the use of batteries, both because the machinery would be steadily loaded, and because the most efficient type of apparatus could be used as is the case in lighting stations. By the consolidation of railroad properties that has taken place in the last few years single corporations operate electric lines over extended areas. It is the custom to build a number of stations, each running a certain section of the line, the idea being that the decreased cost of copper and the decreased possibility of a shut down would more than compensate for the increased cost of operation and fixed charges. It is, again, important to consider the question whether we have not reached the

point where a single station can be built in such a way that there is little or no possibility of any accident causing a suspension of the entire traffic of the system, and where improved methods of distribution will decrease the amount of copper so that it will not exceed that required by the present method of using a number of generating stations.

If storage batteries are used, the two types of variable load belonging to lighting and power stations demand different types of battery. For lighting stations a considerable capacity is required, while the momentary variations of power stations do not require any great capacity, but demand as great a maximum output as battery manufacturers can obtain.

In water power plants the conditions of economy are different. The location of the plant is, of course, definitely fixed, and the advisability of obtaining a uniform load, by means of batteries, depends upon the local conditions. If the water power is limited, and is less than the demand, then it might be well to use batteries in order to increase the amount of salable power. Again, if the development is expensive, it might be cheaper to develop a smaller amount of power, pay for a smaller amount of machinery and increase the output by the addition of batteries. These are questions that can only be decided by a knowledge of the local conditions.

We may conclude that while the practice in large lighting and traction systems is to multiply stations near centres of consumption, yet the economy of a single large station makes it important to consider whether it is not possible to concentrate our power at some point where the expenses will be a minimum and distribute by some of the methods which have in the last few years proved successful and economical. It is important to make the station load steady, and this may be done for continuous current lighting and traction plants by means of storage batteries.

ELECTRICAL DISTRIBUTION.

The distribution of electrical energy to consumers as distinguished from its transmission to long distances, has been largely accomplished by the agency of continuous currents although alternating currents have played an important part in incandescent lighting. As I have stated a considerable proportion of current for lighting is distributed at constant potential on the three-wire system, or at constant current on arc light circuits, while power

for traction circuits is distributed at approximately constant potential at an average of say 550 volts.

I shall first consider the condition of affairs in a traction system in a large city, where a number of suburban lines are operated. If direct distribution is attempted from a single station, it will be found that when the distance exceeds five or six miles a large amount of copper must be employed to prevent both excessive loss and excessive variation of potential on the lines. On suburban lines it is the latter consideration that usually determines the amount of copper used, and this is especially true on lines where there is a considerable excursion traffic. Even in the city itself, the supplying of sections at distances three or four miles from the station may require so much copper that it would be less expensive to operate separate stations. Several methods other than the direct method may be employed to remedy these difficulties. For outlying lines where the traffic is mainly of the excursion order, being variable both during the day and for different seasons, boosters may be advantageously used. It is perhaps best from reasons of economy to run the boosting dynamos from motors. These dynamos are series-wound and are connected to feeders of such resistance that the fall of potential in the wire for a given current is compensated for by the rise in voltage of the booster. There is a decreased cost of copper incidental to this system, due to the fact that the drop is not limited by considerations of regulation—the voltage at the end of the feeder being constant—while the transmission is at an increased potential. If the average station potential is 600 volts, and it is boosted 300 volts, then the copper for a given loss would be decreased in the ratio of 36 to 81. The booster system has the advantage of the direct system when the cost of the additional apparatus together with the increased loss on the line, capitalized, is less than the increased cost of the copper necessary to produce the same result by the direct system. Whether the balance is in favor of one or the other depends on the distance and the variation of the load, and it is indifferent whether the variation in the latter occurs often or not.

If any transforming device is employed to feed a distant section of the line it must be remembered that the capacity of the device must be great enough to look out for the maximum demand on this section. Suppose now that we wish to feed some suburban line where the load has considerable momentary fluctuation.

tuations but where the traffic is moderately constant during the year. In this case the booster could be used with a storage battery at the end of its feeder, the battery supplying the line. The advantages of this combination are greater than with the simple booster and in many cases they will compensate for the interest and depreciation on the battery and the loss in it. If the arrangement is properly made, the load on the booster and line wire will be practically constant, thus decreasing the capacity of the booster to that required for the average load, while less copper will be required for a given loss. As to the latter point, suppose a given amount of power is to be distributed in 24 hours, say 200 amperes at 600 volts, if the load is uniform, the loss will be proportional to $200^2 \times 24$ hours. If it is all distributed in 12 hours, the loss will be proportional to $400^2 \times 12$ hours, or twice as much. So in the case of the steady load the same power could be transmitted with the same loss with half the copper. It makes no difference whether the variation extends over 12 hours in 24 or occurs every other minute, the result will be the same. It is apparent then that it is of the utmost importance to keep the line steadily loaded, as well as the station, and this points to the location of the battery near the points of consumption and not in the station. By this system—a booster with storage batteries—it is possible, assuming the same loss, to transmit power to a distance of ten miles with approximately the same amount of copper that would be required for a five mile transmission on the direct system. It would increase the economical radius of distribution twice and the area of distribution four times. A single station could economically supply lines within distances up to ten or twelve miles. If it is desired to still further increase the radius of distribution, it is possible to do this by employing some of the alternating current methods that have come into use. I will discuss these methods later, but at this point I may remark that the use of stationary and rotary transformers permits the energy to be transmitted in the form of alternating currents, and to be changed again into continuous currents of any required voltage. These rotary transformers supplied by an alternating current which is transmitted from the station at a high voltage, may be used to feed the line directly or they may be used to supply storage batteries which are connected to the line. In the latter case we have the advantage of decreased size of apparatus, of steady load on the station, and of a minimum cost of copper on the line;

which system it would be best to employ would depend upon the distances and the character of the line and load.

Of the systems that I have proposed for city and suburban distribution from a single station, three have been successfully employed, namely: the booster system; the booster system with batteries, and rotary transformers operating directly on the line. When we consider the advantages of a single station and a steady load, it seems evident to me, that many of the large traction systems would do well to concentrate their stations into one and to use the booster system with batteries for their outlying lines, and if necessary use rotary transformers for lines beyond the limit of ordinary suburban work. As to the possibility of the complete shut down of such a station, we have reached such a point in the construction of machinery, both electric and mechanical, that with a proper reserve, a careful system of duplex steam piping, and with fire proof construction of the station, such a possibility may be disregarded; while the batteries would look out for any momentary interruption on the feeders.

CONTINUOUS CURRENT LOW VOLTAGE DISTRIBUTION.

Some of the most important stations supplying incandescent lamps are operated on the three-wire continuous current system. In the last few years a considerable advance has been made in the sale of power for motors from these stations, and this has increased the revenue and has given better average output. The tendency in this country has been in the direction of using storage batteries in such stations, and abroad practically every continuous current station uses batteries. As in the case of traction systems it has been the custom in large cities to build a number of separate stations instead of building a single plant and distributing from it. The batteries have been placed in the stations themselves, and no attempt has been made to decrease the amount of copper used by employing a number of centres of distribution and giving the main feeders a steady load. The same considerations that apply to stations for traction work will also apply to stations used to supply lights and the same methods of distribution may be used. It would unquestionably be more economical, in many instances, to use single stations, to transmit power from these stations to centres of distribution, where batteries may be located and to distribute from these centres on a three-wire system. A case in point is the system used at Budapest, where the energy

is distributed from the central station to rotary transformers at sub-stations, these rotary transformers feeding batteries, current being distributed from these batteries on a three-wire system. The reports of the operation of this station show that it is both economical and successful, and it might well be copied by some of the companies in this country. The gross receipts of some of the large illuminating companies bear such a large proportion to the company's stock, that a comparatively small saving in operation would mean a considerable increase in the dividends, and there is no doubt in my mind that by using one power station, with battery sub-stations for distribution, that the operating expenses can be considerably decreased.

ALTERNATING CURRENTS FOR LIGHTING.

Alternating currents have been employed for lighting in this country, and they have been especially valuable where a district is to be supplied in which the distances are considerable as compared with a number of customers. It has been almost the universal custom to supply small transformers for each consumer, and while the average size of transformers is greater now than it was a few years ago, yet they are comparatively small. No power has been supplied from such stations, and although alternating arc lamps are used to a limited extent, yet the number is not increasing, and in some cases continuous current arc lamps have been substituted for the alternating. Under these conditions the load on the station is even more variable than in the case of a continuous current supply where motors may be employed, and the constant loss due to the large number of small transformers used, places this system at a disadvantage as compared with the continuous current system. The great advantage it possesses lies in the increased area of distribution rendered possible by the high voltages that are used, together with the possibility of locating the stations where power can be cheaply made. Abroad in the last few years most of the new stations that have been built use continuous currents, although some years ago the greater proportion of them were alternating current stations. It is also the custom abroad to use sub-stations with large transformers for distribution, thus doing away with a considerable part of the constant loss due to the small transformers used here. It is not possible, at the present time, without greatly complicating the system, to obtain a steady load on the station, and the

only question that arises is the value of sub-stations, and the possibility of using some form of alternating current other than the single-phase.

METHODS OF ELECTRICAL TRANSMISSION.

Coming to the question of transmission of electrical energy as distinguished from the supply to customers from distributing centres, there have been great advances made in the last few years, and these mainly through the introduction of multiphase alternating currents. Single-phase alternating currents permit the transmission of power to long distances and its distribution for lighting purposes. It is also possible to supply power from such circuits to large motors working under a steady load. It is not possible, however, to distribute power economically for ordinary uses. As most long distance transmission schemes contemplate the substitution of electric motors for steam engines, and as their success will, in many cases, depend upon the possibility of such substitution, single-phase alternating currents are not at present able to comply with the conditions imposed by the desired service. The introduction of multiphase alternating systems, where two or more alternating currents are employed, the currents differing in phase, has completely changed the situation with respect to long distance transmission. I shall consider briefly the possibilities of such systems and their value as compared with any direct current system.

CONTINUOUS CURRENT TRANSMISSION.

The first long distance transmission plant was operated by the continuous current system, and even now plants are being built in which continuous current of high potential are used to transmit energy to distances up to 15 miles. As compared with transmission by means of alternating currents, we will find that the continuous current system possesses some advantages and some disadvantages. If we consider the relative cost of the copper in the line for a given amount of power transmitted and for a given maximum potential between the conductors, we will find that the relative amounts for the continuous current and the different alternating current systems, will be as follows:

Continuous Current.....	100
Single-phase Alternating.....	200
Two-phase ".....	200
Three-phase ".....	150

We see then that the continuous current has a marked advantage over the alternating current systems as far as the cost of copper is concerned. There are, however, certain practical disadvantages belonging to this system. The high voltages necessary for long distance transmission make it impossible to distribute the current at the receiving end without first reducing the voltage. With continuous current this can only be done by employing a rotary commutator of some kind. A plan which has been practically and successfully used has been to run a number of dynamos in series at the generating end of a line, while at the receiving end are a number of motors, also arranged in series, which are used to drive other generators to give the required type of current and the desired voltage. It has not been found possible to make either dynamos or motors of any great output, as there are practical difficulties in running dynamos of high potential where the current taken from them has a considerable value. M. Thury, has installed a number of continuous current transmission plants that have apparently given excellent results. At Biberist, a transmission of 15 miles is employed. At Brescia, 700 H. P. are transmitted over 12 miles at a maximum of 15,000 volts. M. Thury states that generators for 45 amperes can be constructed up to 3000 volts, and he thinks that 4000 could be successfully used. These machines, however, are small when compared with the 5000 H. P. dynamos in use at Niagara, for instance, and where the transmission is a large one the great number of machines necessary would be a serious objection to this type of transmission. It will be seen that the greatest possibility of trouble, in such a transmission, lies at the ends of the line, in the generating and receiving apparatus. It is necessary, no matter what our voltage is, that both the dynamos and motors shall be directly subjected to it, and this with commutated machines will always be a source of danger. If we are to do any considerable amount of lighting from such a station, our energy for this purpose undergoes three transformations before it reaches the lamps, and the efficiency would not be so high as in a corresponding alternating current system. It would hardly be possible to supply motors for ordinary work at the high voltages used for transmission, and the current for them would have to be transformed in the same manner as the current for the lamps. It must be recognized, however, that this system has been successfully used and has given excellent results in a few cases of transmission. Its great advan-

tage lies in the decreased amount of copper as compared with the alternating systems, and in the absence of induction effects, which are a drawback to alternating current transmission.

TRANSMISSION BY ALTERNATING CURRENTS.

A large proportion of the transmission plants that have been installed in the last few years have been of the alternating current type. These have, as a rule, given satisfactory results, and the installations that are now being erected or planned are almost exclusively on an alternating current basis. The great advantage of this system lies in the fact that it is possible to change the voltage of the current without the use of rotating apparatus, and at once economically and safely. Low voltage dynamos may be used, the voltage may be increased in any desired ratio by stationary transformers, the energy may be transmitted at an increased voltage and at the receiving end the voltage may again be reduced by transformers. If we compare this method with the continuous current system, we will see that to obtain an alternating current of the required pressure at the receiving end of the line, we would use the same number of transformations required by the continuous current system. We have the great advantage, however, that our changes in voltage have been obtained by the agency of stationary apparatus, which is much cheaper, is more efficient and is safer than that required in the continuous current system. It is possible to increase the voltage by means of transformers to almost any value with perfect safety and with an efficiency as high as 98 per cent. or 99 per cent. If then our alternating current, when it has been reduced at the receiving end, is as valuable for distribution as the current obtained by the direct current system, there will be no doubt that alternating transmission has great advantages over continuous currents.

I have spoken of the relative amounts of copper required by the single-phase, two-phase and three-phase alternating currents. I do not think it necessary to explain minutely the difference between these systems, as they are well understood. In a single-phase system a single alternating current is used. In a two-phase system two alternating currents, whose phases differ by 90 degrees, are employed, while in the three-phase system, there are three currents differing in phases by 60 degrees. I shall consider the characteristics of these three systems, as there has been much discussion

especially as to the relative value of the last two of them for transmission work. I shall not discuss the various modifications of the systems, but shall confine myself to general considerations. There is no single-phase motor in successful commercial operation that does not require to be started from rest by some outside means. This prevents a single-phase current from being used at the present time for power distribution; and as, in most transmission, the distribution of power is an important item, single-phase currents are not suitable for this purpose. In a two-phase system the currents are usually carried on separate pairs of wires, while in the three-phase system, three wires are generally used, a common return being unnecessary as the sum of the currents is zero, unless the circuits are unbalanced. In distributing on the three-phase system, a fourth wire can be employed, as it gives an advantage in the amount of copper used.

In all these alternating systems the great difficulty lies in the fact that the inductance of the circuit causes the current to lag behind the electromotive force. This decreases the amount of energy transmitted by a given current at a given voltage; it causes a drop in the voltage of the line, and it increases the armature reaction of the dynamo for a given current. The total inductance of the circuit is made up of the inductance of the transformers, of the dynamos, of the receiving apparatus and of the line. In the case of transmission to very long distances the line inductance is a large proportion of the total, while the inductance of the receiving apparatus depends upon whether lights or motors are to be supplied and upon the construction of the latter. When the different wires of the multiphase system are fed from windings on the same dynamo armature, then the drop in voltage due to any excess of load on one of these circuits cannot be compensated for on the dynamo itself. If the amount of current and the lag of the current is the same for all of the circuits of the system, then it is easy by a compounding winding of the dynamo, or by changing the current in the field winding, if there is no compounding, to keep the voltage constant at either the sending or receiving end. When the load on the different wires of the system is not the same, however, it is, as I have stated, impossible to keep all of the circuits at the proper voltage. Where a two-phase transmission with separate circuits is used, then if the separate circuits are wound on different armatures, each can be regulated to give a constant voltage at the receiving end. This

is the case, for instance, in the large dynamos built by the Westinghouse company for use at the World's Fair in Chicago. The difficulty due to the uneven loading of the circuits is specially marked in the case of the three-phase system, and it is one of the principal objections that have been urged against the employment of this system for distribution. It should be pointed out, too, that it is not enough to balance the quantities of current for the three-branches of the system, but the character of the current must also be considered. A non-inductive load on one wire, with an inductive load of equal value on the others would cause an unbalancing just as if the currents differed in amount. In most of the transmission plants that are being operated and that are proposed, it is required to run both lamps and motors from the same circuits, and while a slight variation of potential on the motors would not cause any particular trouble, yet the successful operation of the lamps requires a practically constant voltage. I think, however, and the same grounds have been taken by others, that in any practical transmission of considerable size, it is possible to so balance the loads that this difficulty will not exist to an extent to cause any serious trouble. When the distributing part of the lines is reached, it is usually the custom when a three-phase transmission is used, to employ four instead of three wires. As for line inductance in the two-phase and three-phase systems, there is no question that the latter has an advantage in this respect. By suitable arrangement of circuits the line inductance can be brought to a minimum, and this is of the utmost importance in long distance transmission. I will not take into account the supposed increased efficiency of three-phase motors and dynamos as against two-phase apparatus, as there is a question as to whether a superiority exists, but simply considering the decreased amount of copper required and the decreased inductance of the line, there is no question, in my mind, that for transmission, the three-phase system is superior to the two-phase. It is well known, of course, that the inductance of the circuit can be, in some measure, compensated for by the use of condensers or over-excited synchronous motors. The first of these remedies is, however, a very uncertain quantity commercially, while the second should be used as much as possible, that is, as many synchronous motors should be connected as is practicable. The best remedy, as things stand at present, lies in the careful construction of the line and the apparatus, so that the effects, although they exist, can be reduced to a minimum.

It has been shown by Mr. Scott, and others, that it is possible to transform a two-phase into a three-phase current, to transmit it and to transform it back again to a two-phase current. This will allow us, if we wish, to use two-phase dynamos for generating the current, to transmit with the advantage incidental to the use of three-phases, and at our reducing end to use two-phase circuits for transmission. This has some advantages as far as balancing the voltage on the circuits go, and it has been proposed in the case of several plants whose installation is being considered.

Looking broadly at the value of alternating transmission as against continuous current transmission, we have a gain in the simplicity and safety in the transmission, and at the distributing end the use of multiphase currents enables us to supply both lamps and power with an economy and success comparable to that of the continuous current system. If it is necessary to use continuous currents for certain types of distribution at the receiving end, they can be obtained by the use of rotary transformers, by which the alternating current is transformed into a continuous current. These machines have approximately the efficiency of corresponding continuous current dynamos, while the output for a given size is about 50 per cent. greater.

POSSIBLE VOLTAGES AND DISTANCES OF TRANSMISSION.

A number of calculations have been made as to the possibility of transmitting electrical energy to very long distances. If the question of cost of transmission alone is considered, then where water powers or culm heaps are within distances of 100 miles of some large centre of consumption, it has been shown that it would be profitable to generate and transmit electrical energy. In these calculations, however, voltages are assumed that have never been employed for commercial plants, and whose availability is problematic, while sufficient stress is not apparently laid on the question of the reliability of the power. If the industries of a large city depended upon a single transmission plant, it is evident that the question of reliability is of paramount importance. Where energy is supplied to manufacturers, to street car systems, and for lighting, a break down that would involve the cutting off of current for a day would mean an enormous pecuniary loss to the community. As the distance of transmission increases, the possibility of accident is increased in greater ratio because we have not only the higher voltages to control but

the length of the line that must be looked out for is also increased. The best guide lies in the practical experience which has been obtained in the present transmission plants and the consideration of the difficulties that have arisen and the remedies that have been employed. I have prepared a partial list of the principal transmission plants that are now in operation.

Name.	Type.	Distance in Miles.	Line Voltage.	Horse Power	Remarks.
Ouray, Col.	Direct,	4	800	1200	Successful, increasing.
Geneva, Switzerland	"	20	6600	400	Successful.
San Francisco, Cal.	"	12	80-0	1000	Successful, 9 years.
Brescia	"	12	15000	700	"
Pomona and San Bernardino..	Single phase	13 1/4 to 28 3/4	10000	800	Successful, increasing, 4 yrs.
Telluride, Col.	"	3	3000	400	To be increased, 3000 H. P.
Bodie, Cal.	"	12 1/2	3400	160	Successful
Rome, Italy	"	18 1/2	6000	2000	Increasing to 9000 H. P., 3 yrs.
Davos, Switzerland	"	2	3660	600	Successful.]
Schongelung, Germany.	"	4 1/2	2600	820	"
Springfield, Mass.	2-phase Alt.	6 1/2	3600	820	"
Quebec, Canada.	"	8	5000	2130	"
Anderson, S. C.	"	8	5500	200	"
Fitchburg, Mass.	"	2 1/2	2150	400	"
Winooski, Vt.	3-phase,	2 1/2	2500	150	"
Baltic, Conn.	"	5	2500	700	"
St. Hyacinthe, Canada	"	5	2500	600	" 2 years.
Concord, N. H.	"	4	2500	5000	" 2 years.
Fresno, Cal.	"	35	11000	1400	" to be increased.
Big Cottonwood to Salt Lake City, Utah.	"	14	10000	1400	"
Lowell, Mass.	"	6 to 15	5500	480	"
Sacramento-Folsom, Cal.	"	24	10000	4000	1 year.
Redlands, Cal.	"	7 1/2	2500	700	3 years, extending lines in other towns.
Lauffen to Frankfort, Ger.	"	100	30000	300	(Experimental.)
Lauffen to Heilbronn	"	9	5000	600	Successful.
Oerlikon Works, Zurich, Switzerland	"	10 3/4	13000	450	"
Portland, Oregon	"	12	6000	5000	"
Silverton Mine, Col.	"	4	2500	400	" to be increased.

It will be seen that the longest transmission is at Fresno, Cal., the distance being about 35 miles. The highest alternating voltage used is 13,000 volts at Zurich, Switzerland. The highest direct potential is 15,000 volts at Brescia.

All of these plants are working successfully, and this fact will lead to still longer transmission and higher voltages. No limit of either distance or potential has as yet been reached. If we consider the record of the present transmission plants, we can safely say that it would not be going outside of the safe limit of development to transmit at least 50 miles at a potential of 20,000 volts, provided the energy could be delivered at such a price as to be considerably lower than the cost of a corresponding amount of

energy obtained from a steam plant. This, of course, is a matter of local condition entirely, and the commercial value of such a transmission will depend upon local conditions.

LONG DISTANCE TRANSMISSION FOR RAILROAD WORK.

The possibility of long distance electric railroad lines is intimately connected with the possibility of long distance transmission of power. We have seen that it is possible to transmit considerable distances from a single station. The current so distributed is not, however, such that it can be applied directly to railroad motors, but it must be transformed at points along the line, the distance apart of these points of distribution depending upon the system that is employed. At present continuous current motors are used, and considerations of safety would lead us to use line potentials not greater than 700 volts. By distributing rotary transformers at distances of five or six miles apart, we would be able to supply motors with current without any great investment in copper. The amount of copper required, could be still further reduced by using rotary transformers with storage batteries thus keeping a constant load on the transmission line. It will be found, however, that on any long distance railroad line, the load on any section of the line is exceedingly variable and the discharge rate of the batteries will have to be very high in order to prevent excessive cost for our reducing stations. It is doubtful whether we have reached a point in battery construction that this system of transmission would be economical. It is certain, however, that when the distances are comparatively short, say within 15 miles, and where the traffic is not evenly distributed, that rotary transformers, with or without batteries, can be economically employed for railroad work.

CONCLUSIONS.

My conclusions, subject always to the influence of local conditions, are as follows:

1. In both direct current lighting and traction systems, where the power is generated in or near the area of distribution, it is best to use one station situated at the most economical point for producing power.
2. In the case of the traction systems, when the economical area of direct distribution is passed, boosters should be employed directly or in connection with batteries, to a distance of ten or

twelve miles from a station, and beyond this rotary transformers, whether with or without batteries, should be used.

3. In the case of direct current lighting systems, the energy should be transmitted to storage batteries situated at centres of consumption either directly or by means of a rotary transformer and distributed from them.

4. Where batteries are used it is best to place them at the end of feeder wires to obtain the advantage of a constant load on the wire.

5. The best system for the long distance transmission of energy, for general purposes, is the three-phase alternating system.

6. Commercial transmissions are in successful operation for distances of 35 miles, and for voltages as high as 15,000 volts.

Experience with these plants shows that the transmission to 50 miles with a pressure of 20,000 volts is practicable, beyond these limits the transmission would be more or less experimental.

DISCUSSION.

MR. C. P. STEINMETZ:—I have been very much interested in the problem of power transmission and distribution, discussed by our President, and while his paper is so complete that I cannot expect to add anything essentially new, still less criticise it, I would like to make a few remarks, especially on the rotary converter system.

In railway circuits, wherever the distance is too great for direct feeding from the continuous current generator, the booster is recommended for lines of moderate length, the rotary converter for greater distances. It is probably not generally appreciated that the rotary converter is not a mere transformer from alternating to continuous current, but shares with the booster the feature—valuable in a railway system—to compound or even to over-compound automatically, or still more in general to maintain any desired continuous current voltage at its commutator brushes, irrespective of load or alternating current generator voltage, within certain limits. While in any stationary alternating current transformer system at constant generator voltage, the secondary terminal voltage must fall off with increasing load, and an automatic compounding of the transformer is impossible, yet the rotary converter shares with the synchronous motor the feature that by varying its field excitation the voltage can be controlled by means of a variation of the phase relation between current and E. M. F. Thus at no load, the rotary converter can be under-excited, so that the counter E. M. F. is below the impressed E. M. F., and thus the current lagging greatly, and the

E. M. F. of self-induction of the whole system thrown more or less in opposition to the generator voltage. The potential is thereby reduced to the desired no-load voltage. With increasing load, the excitation of the rotary converter is increased, and at some intermediate load the counter E. M. F. becomes equal to the impressed E. M. F., and the rotary converters act as non-inductive load, giving thus a lesser drop of voltage in spite of the larger current than at no load, while with still higher load the counter E. M. F. of the rotary converter rises beyond the impressed E. M. F., the current is made leading and the E. M. F. of self-induction thrown more or less in phase with the generator voltage, thus actually raising the voltage, so that in an extreme case the voltage is lowest at generator terminals, and rises, the farther we go from the generator, being highest at the commutator brushes of the converter. By means of a weak shunt field and a very powerful series field, the rotary converter can be made to control the excitation and thus the voltage automatically, and this feature is being made use of to a considerable extent now in power transmissions for railway work.

Such a transmission, interesting by its absolutely automatic control, has been in operation for about two years in Portland, Oregon. The generator at Oregon City feeds directly at about 6,000 volts three-phase into the lines. The distance to Portland is 14 miles. Step-down transformers supply rotary converters of 400 k. w. each, which are greatly over-compounded, while the generators are operated at constant excitation. With an inherent regulation of about 15 per cent. in the generator, a resistance loss of 10 per cent. in lines and transformers, and about 20 per cent. reactance voltage, at the secondary terminals a drop of voltage from no load to full non-inductive load should be expected of about 25 to 30 per cent.; still more at inductive load. Due to the action of the rotary converters, however, the potential at the commutator brushes actually rises from 500 volts at no load to 550 volts at full load, the current being lagging at no load, leading at full load.

This plant is still further interesting by having the rotary converters at Portland operating into the same trolley line, in parallel with turbine-driven direct current generators in Oregon City, 14 miles away.

In low tension lighting circuits, as operated on the Edison three wire system, considerable advantage will be gained by the introduction of the rotary converter. The main disadvantage of the low tension continuous current system is the limited area over which the power can be supplied, due to the comparatively low voltage. This necessitates the location of the station in the centre of distribution, where land, coal and water are more expensive, and requires in cities like New York, Chicago, etc., the operation of a number of stations.

By supplying the generators with collector rings and inter-

linking the stations by high potential lines feeding through step-up and step-down transformers, during the time of light load, and perhaps all through the summer, the smaller stations may be operated as rotary converter sub-stations from the larger stations, and engines and boilers shut down altogether, and started up only during times of heavy load, where all stations may be operated as primary generating stations in the same way as at present.

Going still a step further, all stations may be operated as rotary converter stations by high potential feeders issuing from one alternating central station located outside of the city at some convenient place. The high potential feeders will be supplied with constant alternating voltage, and the control of the whole system effected in the rotary converter sub-stations by lead and lag, eventually, where a very wide range of voltage is required, with the help of stationary induction regulators. Such a system would permit connecting very large motors directly on the alternating lines, and thereby relieve the low tension continuous current system of their reaction.

With the comparison of continuous current and alternating current circuits on the basis of maximum voltage, I can not quite agree. In the disruptive action of high potentials, a certain sluggishness exists, that is, disruption takes place a finite time after the application of the potential. This makes it probable that the disruptive strain of an alternating potential is not proportional to the maximum voltage, but less. On the other hand an alternating electrostatic field may cause deterioration of the insulating material by mechanical vibration, by heat due to electrostatic hysteresis or similar phenomena not met with in continuous potentials. Continuous potentials, however, offer a formidable source of danger in their electrolytic action, which does not exist in alternating circuits. In the absence of comparative tests, it is therefore not safe to compare continuous and alternating circuits on the basis of the voltage, and it is quite possible that according to the circumstances, sometimes the alternating and sometimes the continuous electrostatic strain may be more severe.

It is gratifying to see that the voltage used in transmission lines has been constantly increased. While a few years ago 3,000 volts were hardly considered commercially safe, now 11,000 and 12,000 volts are used extensively, and 15,000 to 20,000 volts discussed. The danger limit is reached in the high potential lines; not in the step-up and step-down transformers. Transformers can be built and operated safely at voltages far beyond anything ever thought of for power transmission. Only a few months ago I was able to reach by stationary transformers a potential of 160,000 volts effective, or nearly a quarter of a million volts maximum,—by the way, probably the highest alternating voltage ever experimented upon by man, if we leave out electrostatic

charges and oscillatory discharges as limited power phenomena, while in my case I had practically unlimited power,—a 100 k.w. motor—behind the 160,000 volts. In line insulation considerable progress has been made and insulators can now be secured which will not be pierced below 50,000 or 60,000 volts effective alternating potential in dry weather. When damp, in fog or rain, a considerable lower voltage will leak or creep over the insulator surface and thus short-circuit the line, and this brings us to the real limitation of transmission voltage which exists at present: the climate. In a perfectly dry climate I should not hesitate to consider 20,000 or even 30,000 volts quite safe, while in a very damp and foggy climate, in rain and sleet, half this voltage may be decidedly unsafe.

MR. TOWNSEND WOLCOTT:—Some little time ago, I think about three years ago, an eminent English engineer referred to the continuous current as a nearly obsolete system, especially so far as distant transmission is concerned, and some of my acquaintances here thought that I was very much behind the times because I could not see it quite in the same light at that time. My position was, without placing any limits on the future possibilities of the alternating current, at that time the continuous current was certainly very far from being obsolete. It is interesting to note this evening that the highest voltage which is mentioned as being in successful commercial operation at the present day is continuous current.

MR. RICHARD LAMB:—Mr. President, I have enjoyed listening to your admirable address, and I would like to make a few suggestions in reference to a detail of long distance transmission. It seems, in the consideration that I have had of the matter, that the main trouble has been commercial—the question of cost of the copper. The alternating current has, by your paper, been advocated for long distance transmission, and it has one feature which I believe will in the near future, cause it to be used almost exclusively for long distance transmission, and that is the skin effect. In Prof. Silvanus Thompson's text-book he states that in a thousand cycles, only one-seventh of the diameter is pierced, and that the greater the number of alternations, the less the proportion of the diameter that is pierced. It follows, that with sufficiently high frequency, after giving due consideration to the amperage to be transmitted, a large, comparatively thin copper tube will make the best conductor.

Now, one of the long distance transmission difficulties, is that of heat in the cable. If we have our large diameter tube, we have a greater area subject to the atmosphere to cool. In some of the experiments that have been recently made in Europe, I understand that simple tubes have been used to very great advantage in distributing alternating currents. They have been comparatively large tubes so far as the diameter is concerned.

I have been told by one of the largest manufacturers in the

country, that he can make his tubes in sections of 100 feet and that they will be sufficiently strong, supported at 100 feet distances, not to be blown down if properly clamped. They will stand considerable strain. These tubes would be made by Mannesmann's process.

European tests have shown that Prof. Silvanus Thompson's experiments were correct, and that with an experimental tube line, using a small alternating motor, they got satisfactory and encouraging results by comparison with a plain copper wire. I believe that in the feeder system, for long distance work on the Erie Canal, copper tubes will be used. A test will be made looking to that object.

I would like very much to hear any comments that the President may care to make upon that subject.

MR. ELIAS E. RIES:—Mr. President, I have listened with a good deal of interest to the valuable paper presented to the meeting this evening, and particularly so because I, myself, have given the subject a great deal of attention. About eight or ten years ago I commenced some experiments with alternating currents with a view to their application to railway work, as it was perfectly clear to me even at that time that if electric railways were to be extended over long distances, if electricity was ever to take the place of steam on trunk line roads, or even if it were to be extended into the suburbs of cities for the operation of ordinary street railways over more than the average municipal distances, that higher transmitting pressures must be used than the direct-current 500-volt systems were employing, and I gave the subject, as I have stated, considerable attention, and subsequently took out what I believe to be the first patents that were ever granted on the application of alternating currents of various types to railway work. At that time and for a long period afterward, the trend of popular feeling on the subject of alternating currents for railway or any other kind of power transmission was rather backward, and I am very glad indeed to hear from the evidence presented in the address to which we have just listened, that during the past few years the opinion held by prominent electricians on that subject has changed. Now, there were several methods referred to in this paper whereby the line losses to which existing electric railways are subject could be minimized and by means of which various types of transmission could be employed, and it was said among other things, that a combination of the direct and alternating current systems could be employed, the alternating being used for transmission, and by means of rotary converters transformed into a direct current at lower potential; also that the three-phase and two-phase alternating current systems had certain fields before them for long-distance work, with or without the use of a secondary battery for maintaining the load factor constant despite the heavy fluctuations that exist in railway work. The employment of a secondary bat-

tery for this purpose, when properly applied, offers an excellent method for the maintenance of the greatly-to-be-desired uniform load, and, in connection with direct-current motors, affords probably the best means for bringing about a maximum degree of economy in copper cost for a given system of distribution, as well as the maximum efficiency in the operation of the generating plant. It is, however, not necessary that the battery be located on the line in order to accomplish this result, since the desired end can in many cases be effected to better advantage, in my opinion, by carrying the battery upon the cars. This latter plan has certain additional advantages to commend it which I will not now take the time to discuss. As to the relative merits of the single and multiphase systems, however, my own opinion is that, owing to the great simplicity and flexibility of the single-phase alternating current, it is more than likely that that will be the ultimate system to be employed in future for electric power transmission on railways. Considerable progress has been made in recent years in the direction of operating single-phase alternating current motors and making them self-starting. I have done some work in that direction myself and I do not think I am saying too much when I predict that within a comparatively short time we will have at our disposal motors of that type which will be capable of successful railway work, being self-starting and furnishing a reasonably satisfactory torque, even at slow speeds which will compare favorably with the work performed by direct-current railway motors to-day. If we are ever to operate long-distance electric railways economically we must run up the transmitting potential as high as the state of the art in insulating our currents will permit, and then transform them down to a safe working potential at sub-stations, or transforming vaults along the line of way, at which ordinary alternating current converters are placed, the lower pressure secondary terminals of which are in connection with the railway conductors. For the time being it is possible and very probable that a great deal of work will be done by converting the alternating transmission current into a lower tension direct current through rotary transformers, as has been said, and that is not, in my opinion, an altogether objectionable system. It is better than being compelled to waste a great deal of copper such as we are in the habit of doing to-day, and it possesses the somewhat questionable advantage of enabling us to use the direct-current railway motors to which we are at present accustomed. But the tendency of modern times is towards simplicity. The question of transmission of electric power for railway work will be no exception, and there can be no doubt that in the present case all the advantages are on the side of a purely alternating current system throughout.

I do not think it is necessary for me to add anything further on the subject this evening, as it has been very ably and fully discussed in its various bearings. But it is a matter that interests

the INSTITUTE and the public in general very largely and I trust that other members will in the near future bring up the matter and throw such additional light upon it as their experience may permit them to do.

MR. NELSON W. PERRY:—The question of distribution of energy in municipalities, that is short distribution, as distinguished from transmission of energy over long distances presents quite a different problem. The two cases are entirely different and distinct. For instance, we find that in long distance transmission of energy, the transmission of that energy in the potential form is usually the cheaper way. I think, Mr. President, you said in one of your former papers that the transmission of coal was effected to-day at about half a cent per ton mile. Now we find in our large cities that while we have got our coal to the depot or to the water front at a cost of say half a cent per ton mile, we are paying fifty cents perhaps per ton mile to get it from the water front to our central station. It costs fifty-seven cents a ton to deliver coal on the sidewalk outside the Duane Street station of the Edison Electric Illuminating Company of New York and to carry away the ashes, and that is a distance of perhaps a mile and a half, not more than two miles, from the water front. Now in respect to distribution in a large city, it is necessary with our low potential system of course to locate our central station in the centre of the district to be supplied where real estate is high. That means that our fixed charges are large, and one of the largest charges in the cost of our energy is the fixed charges. It becomes necessary then that we should reduce those fixed charges to the lowest possible amount. With our present methods I believe it is fair to assume that the boiler-room occupies about the same space as the dynamo and engine room do; that is they are about half and half. The gas engine is a recourse which I have advocated. It would do away with the boiler-room which takes fifty per cent. of the floor space. It would require a little more attendance perhaps than the steam engine, but the stand-by losses would be reduced, and it would permit the location of our plants on property which was cheap and where fuel could be had with the minimum of handling. I recently had occasion to make a few calculations as to the cost of distribution of energy in the potential form of gas. Assuming a gas of .55 specific gravity and with a calorific power such that 25 cubic feet consumed in a gas engine per hour would give a horse power hour under fair conditions, I got some results which astonished me, and which will doubtless astonish others who have not looked into the matter. Assuming a transmission to a distance of 5,000 yards, gas of a specific gravity of .55, and a pipe 12 inches in diameter, and to provide for bends, that there was a 90 degree bend every 200 yards, I have figured out the percentage of power consumed in the transmission under various degrees of water pressure. Under one inch of water pressure we would transmit 500 horse power of

such a gas, the percentage of the power transmitted consumed in transmission would be .007 of 1 per cent. Then going to 10 inches of pressure we would deliver 1600 horse power with a loss in energy of transmission of .07 of one per cent. of the power delivered. The percentage loss in transmission with gas is very nearly directly proportional to the pressure, whereas you know that with electricity it is the other way, and the two curves would cross each other somewhere—just where, would depend upon the conditions. While the gas transmission for municipal distribution would seem to be by far the more economical method, it would not apply at all to the longer transmissions because of the direction of these two curves which would be straight lines approaching each other at a somewhat obtuse angle. The plan which I had in mind was the location of a large plant for commercial purposes on land which was cheap, on the water front or on a railroad where the coal could be handled at a minimum of expense, and the ashes be gotten rid of with very little trouble, and the transmission of that fuel gas to centres of distribution where gas engines would be employed to drive dynamos. Those centres would preferably be centres of smaller radii than usually supplied by central stations or if for any reason it seemed desirable to increase the radius of these districts, and even with the shorter ones, it might be advisable as President Duncan has said, to use the storage battery in order to use the machinery, and plant, and labor that we did employ to the best advantage by operating them continuously at their best output. But it seemed to me that these figures of the cost of transmission, the drop in transmission by gas, is something that is astonishing. I had no idea that I would arrive at any such figures as those when I started to bring out these figures. In electrical transmission when the distance is not very long we allow 10 per cent. Five per cent. would not be economical in many cases, and here we go down, in one case, to the seven thousandth part of one per cent.

MR. J. G. WHITE:—I presume that most of the people present are electrical engineers rather than gas engineers, and are consequently interested in seeing the electrical side of this question fairly upheld. I would like to ask Mr. Perry one question, and that is, what allowance he has made for leakage in his gas transmission, and what allowance it would probably be necessary to make for leakage, assuming that the energy was electrically transmitted. In the gas transmission, so far as I know the subject, the leakage is by large odds the most important item, and the loss in pressure or loss of energy due to transmission is practically negligible, whereas directly the reverse is true with the electrical transmission. I know of a gas plant which is now in operation and distributing its produce through some three miles of pipe, the most distant point being within two miles of the holder, in which the average loss due to leakage is about 43 per cent. Suppose we add to that the .007 of one per cent. for

loss in transmission; then we get a very respectable total. So large an allowance would not be necessary with a well constructed line—one that was kept in good repair; but it would even then be a very considerable item.

MR. PERRY:—I would say that I had not allowed for 40 per cent. leakage in this estimate of mine. A friend suggests that the leakage referred to may have been in a municipal plant.

THE PRESIDENT:—The transmission was certainly very economical; but everyone who has seen an Italian pushing a lot of dynamite in a push-cart must have observed that there was a great deal of energy transmitted with very little expenditure of power. We would hardly, however, consider a push-cart a particularly efficient means of power transmission.

MR. STEINMETZ:—On single phase alternating current motors, inventors have been working since the early days of alternating current distribution, that is for about ten years, and on an average about three or four times every year we have been told by some inventor that the single phase motor is practically perfected, and that we should wait a few months only to see a perfect motor brought on the market,—and we are waiting still.

In the meantime our theoretical and practical knowledge of alternating current phenomena has been vastly increased, so that we can fairly well judge now on the prospects of self-starting single phase motors.

The self-starting single phase motor of the induction type is not a mere fantasy any more, but such motors are listed as standard apparatus by manufacturers, and are in commercial operation. At present, for instance, I am building a 100 h. p. single phase induction motor to go on a 60 cycle lighting circuit, and to start with considerable torque.

It must be understood, however, that the single phase induction motor compared with the polyphase motor must necessarily be less efficient, have a lower power factor, and a larger exciting current, and require a larger current to start with the same torque. That is, if in a polyphase induction motor the efficiency averages from 75 to 94 per cent., according to the size, the power factor from 85 to 90 per cent., the apparent efficiency from 60 to 80 per cent., the exciting current from 20 to 35 per cent., and the motor will start with full load torque, while consuming not more than full load current, the single phase induction motor will give only from 65 to 85 per cent. efficiency, from 70 to 85 per cent. power factor, from 50 to 70 per cent. apparent efficiency; it will have an exciting current from 35 to 60 per cent., and require from two to three times full load current to start with full load torque, or develop from one-third to one-half full load torque with full load current in starting. Indeed a very satisfactory and efficient single phase motor can be produced, but the same motor operated as a polyphase motor would be still better.

The single phase synchronous motors are not self-starting, but

have to be started by some means, either as polyphase motors by phase splitting devices, or by means of commutators, in very small motors, or by a small induction motor or direct current motor. When running at speed, however, they are practically as good and efficient as polyphase synchronous motors, and produce no lagging currents, but when properly excited give 100 per cent. power factor, and can even be made to compensate for lagging currents, by over-excitation.

Such motors have been used for power transmission, and the oldest power transmission by alternating currents in this country, the Walla Walla plant,—still in operation, I believe,—consists of a pair of 60 k. w. high-frequency alternators, one as generator and the other as motor. The method of starting the plant is quite interesting. The generator has a 500-volt exciter, the motor a 110-volt exciter. The line consists of two wires in parallel. In starting, the 110-volt exciter of the motor is started as continuous current motor over one of the lines by the 500-volt exciter of the generator, and starts the synchronous motor. When up to speed, the motor is synchronized with the generator over the second line, then the continuous current starting line disconnected and thrown in parallel with the other line.

Other alternating single phase motors, as series and shunt motors or commutator motors in general, need hardly be discussed, since they have proved a dismal failure even in such small sizes as fan motors. As a starting device, the commutator is used on synchronous motors to a limited extent.

MR. RIES:—I wish to state that I succeeded some time ago in constructing a synchronous motor that was self-starting. However, I have not arrived at that point where I would recommend that motor for use as a practical railroad motor. It was rather of smaller size and for that reason I did not state that a successful alternating current motor, single phase, self-starting, was now immediately available, but that I hoped and thought that it would be very shortly. I am glad to note, however, that Mr. Steinmetz is willing to admit, as we most of us know, that there are in use successful single-phase alternating current motors, even though their efficiency as compared with the two-phase motor or with a direct-current motor may not be very large. However, the point must not be lost sight of in discussing the transmission of power for railroad work, that in using a two-phase or three-phase motor it renders necessary the use of two or more overhead trolley wires or other line conductors instead of a single one, still using the ground, of course, as the return. That necessity involves objections of so serious a nature that we can well afford to sacrifice something in the efficiency of the motor—a single-phase motor—if by that means we are put in a position to operate our lines by means of high-tension transmission and low-tension working currents as I originally proposed. Another very great point in favor of the single-phase alternating current system that must

not be overlooked is the exceeding simplicity, mechanically and electrically, of the alternating current motor, and its ease of control and freedom from faults and serious breakdowns under excessive loads as compared with the railway motors now in general use. These advantages are sufficient, in my opinion, to more than counterbalance the losses due to their, at present, slightly lower electrical efficiency. It was in that view of the situation that I say that in order to have the greatest simplicity in the system, and simplicity is required if it is ever to be a permanent success, the single-phase alternating current system is the one that will in all probability be adopted. Of course, as in every other direction of development and progress, we must make use of those things we have, before flying to others that we know not of, or at least, have not in immediate hand. The next year or two will probably see a great many long-distance electric railways installed in which rotary transformers are employed. There is no objection whatever to rotary transformers except that they involve the use of moving mechanism, and still retain that undesirable and apparently indispensable commutator; and if you place a rotary converter at various sub-stations along the line, it requires one or two attendants at each station to look after them and keep them in order. Whereas if you put down a static converter with no moving parts whatever, it can run itself without any attention; you can bury it out of sight in a hermetically tight box or vault or any other suitable receptacle and it requires no attention whatever, and everyone must concede that such a system as that, is by far the most desirable one, and, as I have already said, we can easily afford to sacrifice a little in the efficiency of our motor if by that means we can operate a system possessing so many points of superiority and so many vastly greater advantages than the direct-current system that we now have, or than the two-phase or three-phase system, with its multiplicity of wires, that has been spoken of.

MR. STEINMETZ:—While I do not share the opinion that single phase alternating current motors will find an application in the near future for railway work, polyphase alternating railway systems will probably be installed to a certain extent soon. They have, indeed, the disadvantage of requiring two trolleys. However, as you all know, one of the largest street railway systems in this country is operated on the double trolley system, and operated successfully, and the objections to the double trolley are very much less on long distance high speed roads, and on suburban and interurban lines, where switches and crossings are few, and such roads would constitute the proper field of application for three phase railways.

Regarding self-starting single phase synchronous motors, no such motor has ever been built. Of course, a single phase synchronous motor can be supplied with a commutator to start as series motor, and will then start, provided that the load is light enough, and the

motor is small enough to come up to speed before the commutator has burned up.

MR. WOLCOTT:—I would like to ask for information if there is any polyphase railroads in operation now, except the one at Lugano, Switzerland.

MR. STEINMETZ:—There is no three-phase railway in operation in this country, but in Europe I have heard that one small road is being operated. I have been doing a considerable amount of experimenting during the last two years on three-phase railway motors, with entire success, and in all probability some roads will soon be equipped with such motors.

[Adjourned.]

BOOKS, ETC., RECEIVED BY THE INSTITUTE.

ROENTGEN RAYS AND PHENOMENA OF THE ANODE AND CATHODE. Principles, Applications and Theories. By Edward P. Thompson, M. E. E. E., Member A. I. E. E. Conclusion by Prof. William A. Anthony, Member A. I. E. E. and Past President. 190 pages, 105 cuts. New York, D. Van Nostrand Co., 1896.

A description of experiments by various investigators leading up to the discovery of the X-rays by Prof. Röntgen; also details of various demonstrative experiments made in Europe and America since the announcement of the discovery.

ARMATURE WINDINGS OF ELECTRICAL MACHINES. By H. F. Parshall, Member A. I. E. E.; and H. M. Hobart, S. B., Associate Member A. I. E. E. 362 pages, 129 diagrams and plates. D. Van Nostrand Co., New York.

Working drawings, descriptions, and formulas of different forms of armature windings for continuous and alternating currents.

ELECTRICAL TRANSMISSION OF ENERGY. By Arthur Vaughan Abbott. Member A. I. E. E. 586 pages, 281 cuts, 74 tables, 9 folded plates. D. Van Nostrand Co., New York.

The Properties of Wire; The Construction of Aerial and Underground Circuits; Electrical Instruments; Methods of Electrical Measurement; Continuous Current Conductors; Conductors for Alternating Currents; Series Distribution; Parallel Distribution; Miscellaneous Methods and Long Distance Transmission; The Cost of Production and Distribution.

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